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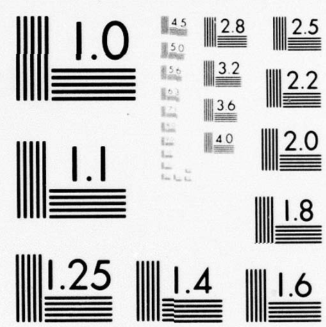

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FOUR STELLAR DIAMETER MEASUREMENTS BY A NEW TECHNIQUE: AMPLITUDE INTERFEROMETRY

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ABSTRACT

alpha alpha alpha

Diameters are reported for four late-type giant stars, α Boo, α Ori, α Tau and β Peg. The diameters were obtained with a new kind of interferometer designed expressly to operate in the presence of atmospheric fluctuations. The new technique, called Amplitude Interferometry, is briefly described. The results include measurements of α Ori at several wavelengths.

beta alpha

Subject headings: stellar diameters - Michelson interferometry - Amplitude Interferometer

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I. INTRODUCTION

The original stellar diameter measurements were made by Michelson and Pease at Mt. Wilson, using a 20-foot beam on the 100-inch telescope (Michelson and Pease, 1921), and using the 50-foot beam (Pease, 1931). In these measurements the diameters were determined by the value of the linear separation of two apertures for which the fringe visibility vanished.

In the last several decades, a variety of methods have been developed to obtain quantitative results which are independent of atmospheric turbulence. In particular, these include: intensity interferometry (Hanbury Brown, 1968); lunar occultation; and speckle interferometry (Labeyrie, 1970, Gezari, et. al., 1972). In addition, several attempts similar in type to the Michelson approach have been made to make quantitative measurements of stellar fringe visibility using two-aperture predetection interferometry with modern detectors and electronics (Elliot and Glass, 1970; Glass and Elliot, 1972; Beavers, 1966).

We report here the first measurements of stellar diameters using the technique of Amplitude Interferometry which was proposed at the Woods Hole Summer Study of Synthetic Aperture Optics (Currie, 1967 a, b) and which has been developed at the University of Maryland. Early results of this approach were reported by Currie (1971). This paper reports the first modern application of Michelson stellar interferometry to successfully produce repeatable diameter measurements in the presence of the turbulent atmosphere.

II. THE AMPLITUDE INTERFEROMETER

We present here a brief description of the technique; a complete description and analysis will be published separately (c.f. Currie 1967a, b).

Amplitude Interferometry is quite similar to the classical two-slit stellar interferometry of Michelson. It differs in that the two recollimated beams are combined, for interference, in a parallel fashion so that they produce a field of uniform illumination. In addition, it uses an electro-optical detection scheme designed to operate on light which has passed through the turbulent atmosphere. The basic optical configuration is shown schematically in Figure 1. The light from the primary is recollimated and the mask selects two small beams. They are each divided and superimposed by a Köster prism to produce two output beams which are the interferometric combination of the input beams. The fluctuations in the intensities of the two beams leaving the Köster prism basically contain two components, one anti-correlated and the other correlated. The amplitude of the anti-correlated component is directly related to the fringe visibility of the source. The variation in time of this component is determined by the relative instantaneous optical path length for the two beams through the atmosphere and telescope optics. A result of the optical configuration is that the anti-correlated component is modulated by the random fluctuations of the atmospheric <u>seeing</u> and by telescope guiding. The correlated component, on the other hand, is a measure of atmospheric <u>scintillation</u>. The Amplitude Interferometer, by the virtue of the Köster prism and the use of two detectors, permits the separation and quantitative measurement of these two components.

The detectors used to measure the intensity of the output beams are uncooled Bendix Channeltrons, operating in a single photoelectron counting mode. They serve as very stable detectors with very low dark current. These properties are desirable because the fringe detection is accomplished by comparing the outputs of the detectors in times short compared with the time in which the intervening atmosphere changes its structure due to turbulence. A digital correlator of our design examines the two pulse trains produced by each of the detectors. Pulse pairs are recorded as correlation events if they are separated by less than some time interval (typically 1 millisecond) which we can change depending on the atmospheric condition and object brightness. The correlation events are counted for an integration time long enough to insure complete modulation of the fringes by the atmosphere and guiding, and to obtain enough counts to have sufficient statistical accuracy. The modulus of the mutual degree of coherence (Born and Wolf, 1965) commonly called the "fringe visibility", is given, for ideal instrumental conditions, by $|\gamma|=\sqrt{2}\,(AC-CC/AC+CC)^{1/2}$ (c.f. Currie 1967). Here, AC and CC are the total number of auto correlation (same detector) and cross-correlation events in an integration time. Additional information is recorded to determine a number of instrumental parameters used in the data reduction.

The apparent coherence of the light is reduced by tilts across the aperture, and by relative phase delays that are comparable to the coherence length. The magnitude of the influence of these effects is controlled by the choice of the aperture size (typically 4 cm) and the spectral filter bandwidth (typically less than 100 Å). We require reasonable seeing ($\lesssim$ 3 arc sec) for a satisfactory integration times.

At present we observe unresolved reference stars to determine the magnitude of the corrections due to instrumental misalignments and atmospheric effects. These can result in a correction in the visibility as large as 40%. The largest correction occurs at the maximum separation where both of the above effects are most severe.

We have found that the Amplitude Interferometer produces results which are reproducible from night to night, and which require only moderately good seeing. In clear weather the standard deviation of the measurements within a run is in accord with calculations based on photoelectron statistics. No instrumental dependence on wavelength has been found. The instrument is mounted at Cassegrain focus and can be rotated to any desired position angle.

III. THE MEASUREMENTS

Measurements of the angular diameters of four stars are given in Table 1. The visibility function measured is the Fourier transform of the one dimensional projection of the source brightness distribution, and is thus sensitive to both the diameter and limb darkening. With the presently available sensitivity we determine a single parameter, the "effective diameter" which is the diameter obtained by a best r.m.s. fit to a disk of uniform brightness.

The quantity denoted "standard deviation of the mean" in Table 1 is derived from a comparision of the diameters determined from a number of runs scattered over several nights. This gives the internal agreement over a variety of atmospheric conditions, and it is in accord with theory. The "total uncertainty" is a combination of the "standard deviation of the mean" and our estimates of the various systematic errors due to atmospheric effects, instrumental problems, and data reduction approximations. As we discussed earlier, for a particular atmospheric condition, and for the selected aperture size, bandwidth and correlation time, the atmosphere degrades each measurement of the visibility by an amount which is less than some chosen value.

For a star with $m_v = 2.6$ the total required observation time for a single separation is 3 minutes for an internal precision of 10%. Measurements are usually taken at 4 separations (0.75, 0.60, 0.30, 0.15 of full telescope apertures) to determine a diameter. This measurements result in a precision for the diameter (night to night) of about 10%.

The interferometer measures the visibility with light in a single linear polarization, and the measurements α Ori, α Tau and β Peg were made with the polarization state perpendicular to a line connecting the pair of interferometer apertures.* For α Boo, the measurements were in an elliptical state of polarization due to the 45° reflection from the tertiary mirror in the folded Cassegrain configuration of the 100" telescope.

Betelgeuse (M2Iab) was observed on the 200" telescope, with α And and α Leo as reference stars. The seeing varied from 1.5 to 3 arc-sec (visual estimate). The results for several wavelengths are given in Table 1. The importance of narrow-band diameter measurements for the

* The role of polarization across a stellar disk has been discussed, for example, by Stanford and Pauls, 1972.

study of stellar atmosphere has been pointed out by Faÿ and Johnson (1973). Differences in photocathode responses at the wavelength extremes for the two photomultipliers contribute to the larger scatter at the wavelength extremes. When comparing the effective diameter measurements at different wavelengths, most possible systematic effects are eliminated and the appropriate error estimates are given by the standard deviation of the mean (see Table I). The wavelength dependence of the effective diameter of α Ori is not monatronic as a function of wavelength. This result does not agree well with monatonic wavelength dependence of Bonneau and Labeyrie (1973). However, the comparison is somewhat uncertain because Bonneau and Labeyrie (1973) do not discuss the published errors.

α Ori was observed as a function of position angle in a special set of observations on 20 December, 1972. To remove the effects of dispersion due to the atmosphere, a set of non-deviating chromatic wedges (to be described elesewhere) was installed near focus. Five measurements stepped in position angle by 45° showed no deviation from circular symmetry in excess of 15% r.m.s.

IV. CONCLUSIONS

The diameter measurements of four stars with the Amplitude Interferometer have been presented. The uncertainties of the technique are in accord with those based on photon statistics. The diameters are generally in agreement with those of Michelson and Pease, but wavelength dependence of the diameter of α Ori reported here is not in good agreement with the results of Bonneau and Labeyrie (1973).

Future observations are planned with improved equipment, which will greatly increase the accuracy and sensitivity of the Amplitude Interferometer.

We wish to thank Dr. Horace W. Babcock, the Director of the Hale Observatories, for generous grants of observing time. In addition we wish to thank Dr. Arthur H. Vaughan and members of the staffs of the Hale Observatories and of the California Institute of Technology for excellent assistance in the perparations of our observations. We are extremely grateful to the Astronomy Branch of the Goddard Space Flight Center for large amounts of time used on the 36" reflector during the development of the instrument. This work was supported in part by the AFOSR under grant 69-1729 and in part by NASA under grant NGR 21-002-301. The data reduction was carried out at the University of Maryland Computer Science Center with the support of NASA grant NsG 398. We also wish to thank the large number of persons at the University of Maryland who contributed to the instrument in a variety of ways. Portions of this paper are based on thesis research of two of the authors (S. L. K. and K. M. L.), in partial fulfillment of the requirements for the Degree of Doctor of Philosophy at the University of Maryland.

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TABLE 1

1972 Measurements with the Amplitude Interferometer

Star	Wavelength/ Bandwidth (Å)	Dates	Diameter (")	Standard Deviation of the Mean (")	Total Uncertainty (")	Previous Measurements: Pease* (")	Previous Measurements: Speckle[†] (")
α Boo	5000/100 5100/30	2-5 June 28-30 July	0.026	(0.004)	0.007	0.020	0.022 ± .003
α Ori	4213/68	21 Dec.	0.062	(0.013 est.)	0.017	0.047 0.034	0.067 ± .005 (at 4880 Å)[††]
	5015/77 5024/25	18, 21 Dec.	0.047	(0.002)	0.006		
	5803/95	20, 21 Dec.	0.057	(0.007)	0.009		
	5992/29	18, 20 Dec.	0.057	(0.002)	0.006		
	6336/32	18, 21 Dec.	0.044	(0.009)	0.013		
α Tau	5803/95 6336/32	21 Dec.	0.024	(0.002)	0.005	0.020	Resolved but uncertain
β Peg	5803/95	20, 21 Dec.	0.021	(0.003)	0.006	0.021	0.016 ± .002

*Pease (1931); effective wavelength is near 5750 Å.

[†]Gezari, et al. (1972).

[††]Bonneau and Labeyrie (1973); [redacted].

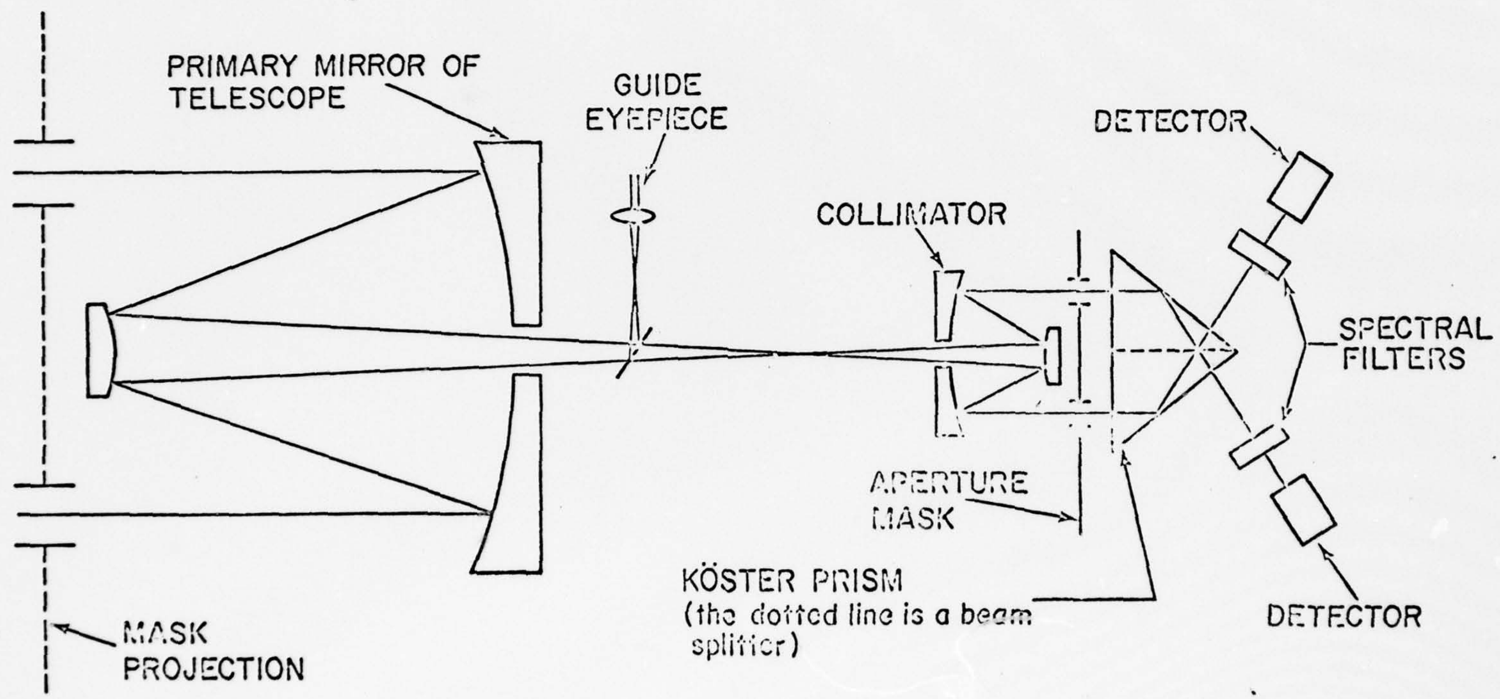

FIGURE 1: Schematic diagram of the optical configuration of the Amplitude Interferometer.

CAPTION TO FIGURE

Figure 1: Schematic diagram of the optical configuration of the Amplitude Interferometer.